

Design of a rib impactor equipment

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Abstract. The human ribs must be analyzed as long and as curved bones, due to their physiology. For the development of an experimental equipment that simulate the application of loads, over the rib in the moment of a frontal collision in an automobile with seat belt, it was applied a methodology that constituted in the identification of needs and the variables which led the design of 3D model, from this it was used the technique of fused deposition modeling for the development of the equipment pieces. The supports that hold the rib ends were design with two and three degrees of freedom that allows the simulation of rib movement with the spine and the breastbone in the breathing. For the simulation of the seat belt, it was determined to applied two loads over the front part of the rib from the sagittal and lateral plane respectively, for this it was made a displacement through a lineal actuator with a speed of 4mm/s. The outcomes shown a design of an equipment able to obtain the load parameters required to generate fractures in rib specimens. The equipment may be used for the study of specimens with nearby geometries to the rib taken as a reference.

1. Introduction

The bone is a biologic element that suffers changes during its growth also depending its location it has a complex geometry. There are several investigations with principal interest on determination and analysis of the mechanics proprieties of the ribcage elements with the objective of establish the answer that suffers chest in a traumatic event.

Those investigations usually search to measure the applied load and the damage caused in the body, either because the impact force which was generated, speed, acceleration or applied compression; the rib fractures are considered as an important indicator, because these are caused by serious injuries and are related specific with injuries in organ and a high mortality rate as a result.

In 2009 was realized an analysis of Time-Frequency by [1] in order to get the mechanics proprieties of thorax, for that purpose; specimens with the absence of pre-existing fractures, lesions or other bone pathology were used. The tests were realized in a seat designed to imitate an automobile standard seat. The impacts were applied using a pneumatic impactor; the impact velocity was 3 m/s. The specimen was successively impacted at three levels: shoulder, upper chest and mid chest. After each test, were found fractures for the number 3 ribs and below, each fracture was described as displaced, non-displaced, mono-cortical or bi-cortical.

For the evaluation of stiffness and kinematic of ribcages in 2010 was designed by [2] a process in which was applied a load to the thorax by a plate connected to an actuator, for avoid a fracture by shearing were used spherical segments as an interface between a loading plate and the ribcage. Were



realized two types of test: unilateral in which was used only one load plate to move a single point and bilateral, in this test two load plates applied a displacement in two points simultaneously.

In 2011 was realized a test by [3] for the analysis and reduction the thoracic injuries in vehicle collisions, for this test it was used a testing machine with a 5 cm wide of nylon belt, which is the width of a standard automobile seatbelt, situated at 40 degrees from a sagittal plane of the body, the load was applied to the thorax by a hydraulic actuator and it distributed by a rigid plate.

The deflection of thorax was measured using a string potentiometer joined to the sternum belt, the force of the loads cells was added for obtaining the reaction force for effective deflection of the thorax under these conditions it was determined for realization of a linear regression of the force versus percent deflection from 0% to 20% of compression.

A study on 2013 realized by [4] reported that the stiffness of the ribs can be evaluated by a horizontal impact test (Fig. 1), for the test, the extremes of the rib were hold to a pair of rotation elements that allow free rotation of the specimen, the test was realized with a horizontal impact by a pendulum with 54.4 kg of mass to a velocity of 1 m/s and 2 m/s. The load was measured with a load cell aligned to the rib center. The test was realized with different sizes of ribs and the conditions of tests are destined for the simulation of a front dynamic impact.

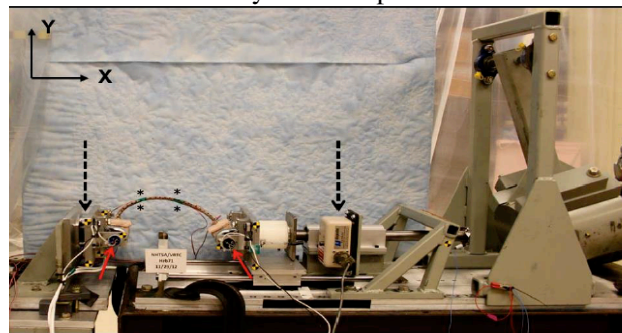


Figure 1. Experimental test of frontal impact by [5].

2. Materials and Methods

2.1. Methodology

For development of equipment design, was used a methodology of design constituted in the identification of needs established by the variables that affects directly the tests to apply on the ribs, which led to the design of a mechanic model on 3D, the construction of the equipment and the performance validation. The parameters of design were:

- Rib's breaking forces.
- Rib anatomy.
- Load 's application points on the ribs.
- Freedom degrees in the equipment.
- Load Displacement.
- Load Application velocity

2.2. Design considerations

During a frontal impact automobile, displacements due a seatbelt on the occupant's body are generated, specifically in the thorax and abdomen. Because of the displacements were defined forces that act on the rib in the impact time, so for the test experimental equipment were determined apply two loads on the front part of the rib, one with sagittal plane relation and posterior with relation to lateral plane of the body respectively for simulate the mechanic of the rib (Fig. 2).

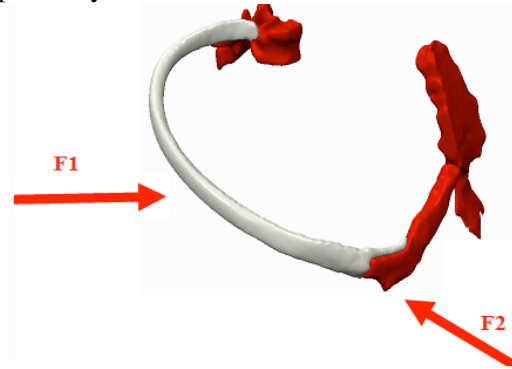


Figure 2. Forces applied on the rib.

The equipment dimintions were defined in relation of the ribs real dimintions; for the specimen; rib number 7 of a male adult person with more than 70 years was taken as a reference.

The natural move of the rib in the moment of breathing was observed to define the freedom degrees of the supports and mechanisms of equipment, for the end of the rib liable to the spine and the torax move up and down in the moment of inspiration and expiration was considered.

For the determination of the force magnitude to apply on the rib structure, was considered a rib with 200 mm of length and the tansversal area with 14 mm, a breaking compression force of the rib with compact structure of 170 N/mm² and with trabecular structure of 2.2 N/mm².

It was determined to realized the test in static conditions, the conducted studies by [5-9] define conditions of applied velocity force between 5 and 16 mm/s, on that basis it was established the applied force over the specimens of 4 mm/s.

2.3. Design for brackets of clamping ribs

For the supports, it was designed a worktable in which a pair of riel were assembly; its function is hold the base supports that hold the extremes of the rib.

The restrictions and freedom degrees of the equipment rib supports were defined in specific anatomy of the rib and the relation of the rib move with the spine and sternum in the breathing moment.

The support A was fixed to the worktable for simulate the rib subjection with the spine, was defined with two freedom degrees to cause the rotation generated for the supports on the subjection elements; the support B was not fixed in the structure, for its attributed of three freedom degrees (Fig. 3).

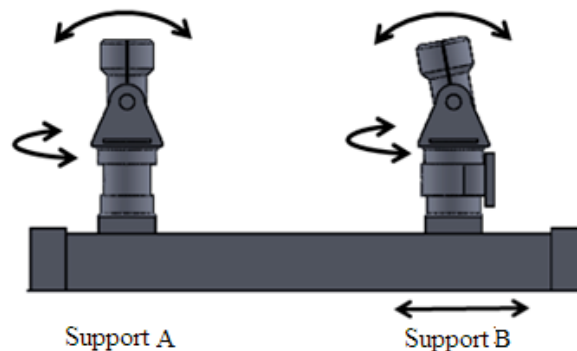


Figure 3. Freedom degrees of the supports

2.4. Movement of mechanisms

With respect to breaking compression force contemplated, was obtained the necessary motor torque for applied the load on the specimen, for that was use the equation (1).

$$\tau = F * d \quad (1)$$

$$\tau = 5950 \frac{N}{mm}$$

The displacement for applying the force on the specimen was defined for a linear actuators located to the top and side of the equipment.

The linear actuator has declared a displacement of 150 mm (L_{max}) because the height of the rib placed in the subjection supports is approximately 140 mm, the displacement of actuator the motor moves to pinion and the wheel to threaded rod were associated, the relation of gears used for transmission of move was 4:1. The step (P) of the threaded rod it's from 2 mm, due to relation of gears (i) the revolution displacement (L_R) was described:

$$L_R = \frac{P}{i} \quad (2)$$

$$L_R = 0.5mm$$

The number of revolutions (R) necessary for specify the displacement for the actuator was defined by:

$$R = \frac{L_{max}}{L_R} \quad (3)$$

$$R = 300 rev$$

For define the velocity displacement of the actuator, was defined the total time (t) associated to velocity (4 mm/s).

$$t = \frac{L_{max}}{v} \quad (4)$$

$$t = 37.5 s \approx 38s$$

2.3 Mechanic 3D Model

For realizing the mechanic 3D model of the experimental equipment of test in ribs (Fig. 4) it was used SolidWorks® for design. The retaining brackets were inserted to the base, its structure and freedom degrees allows movement rotation of supports for adjust of rib geometry. Within brackets are the subjection elements with the function of retaining the extremes of rib in the moment of test.

On the top of the equipment was assembly a linear actuator which is coupled a load support, this actuator moves in descending order to apply a point load in two points, on the side of the equipment was assembly a second actuator, the displacement realized by the actuator to the mobile support and allows applying a front loads on the specimen with relation to sagittal plane of the body.

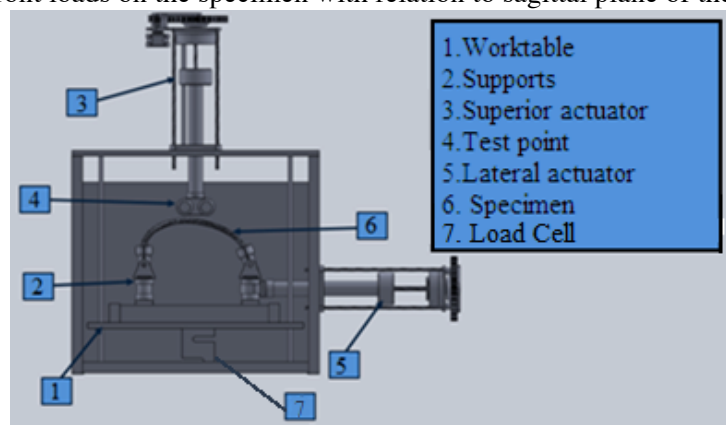


Figure 4. Mechanic 3D model of the equipment.

2.4 Electronic instrumentation

For the function of the equipment were designed electronic circuits (Fig. 5) that altogether perform a specific function with the movement of equipment mechanism for apply the necessary loads on the ribs in the moment of the test and perform the measure of parameter test, through a load cell placed in lower part of equipment.

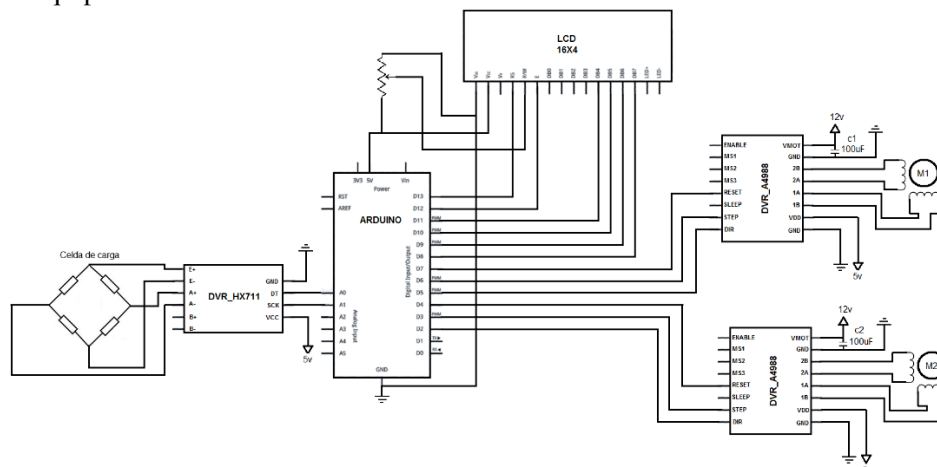


Figure 5. Electronic diagram of the equipment. circuits.

3. Results

With the manufacture of the equipment, it was observed the physical deformation generated on the rib in a situation of a frontal collision with seat belt starting with static force conditions and applying a displacement of 4 mm/s on the specimen.

In the moment of applying the loads on the specimen, it was observed that the displacement of 4 mm passed on by the linear actuator of the superior structure of the equipment generates an increment of flexion than the lateral linear actuator generates on the frontal of the rib (Fig. 6), what caused a displacement of 120 mm before fracture of the rib, concluding that with the point loads that were generated on the front of the rib the experimental test equipment represents a chest compression due to frontal impact.

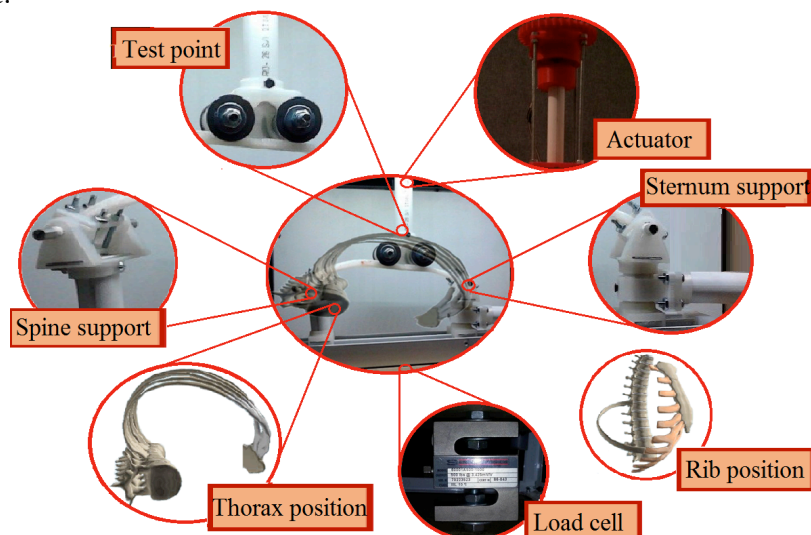


Figure 6 Flexion applied on the rib.

The specimen was obtained by tomography and “fused deposition modeling” technique was used. The specimen used for the test have different properties that a real bone, the modulus of elasticity of the material used is about 10 times lower than the bone, however the design considerations allow apply test in structures that do not exceed the elastic modulus of the bone (170 GPa), it is possible to use similar specimens to those of a human rib having physical properties equal or less magnitude than those established for compact bone physical and geometric properties. Due the structure design and

the biofidelity of the freedom degrees of the supports given to the equipment, the experimental test can be used for evaluate cases which implies changes in the bone proprieties, either due to age conditions or bone pathologies.

4. Discussion

The fracture of the specimen submitted to the test was found in the anterolateral region of the rib near to the extreme from fixed support of equipment, location of fracture is coincident with the experimental works reported by [5]; in comparison to mentioned work; that was realized with dynamics experimental conditions present a double fracture in the anterolateral sites of the rib near to the extreme subjects to the supports. The above mentioned presents a validation of the design of experimental equipment able to simulate a frontal impact representing the chest compression. The development of the impact simulation is a fundamental progress to identify the mechanism of injury in the body due to impacts, however for results are reliable the design of equipment for its study needs to include physical proprieties that are able to represent real behaviour of human body for the biofidelity of equipment, which applied the integration of freedom degrees of the supports that simulate the mechanics of the rib.

5. Future Works

Based on the work done, the followings future works are suggested:

- Perform a test machine to study of the behaviour of the ribs under twisting forces.
- Implement a database in the testing machine that allows a comparison of the behaviour of displacement of ribs subjected to various forces.
- Manufacture an experimental model to evaluate the conditions of frontal and lateral load dynamic load conditions.

Acknowledgements

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